

## **Innovation Self-Efficacy: A Very Brief Measure for Engineering Students**

### **Dr. Mark Schar, Stanford University**

The focus of Mark's research can broadly be described as "pivot thinking," the cognitive aptitudes and abilities that encourage innovation, and the tension between design engineering and business management cognitive styles. To encourage these thinking patterns in young engineers, Mark has developed a Scenario Based Learning curriculum that attempts to blend core engineering concepts with selected business ideas. Mark is also researching empathy and mindfulness and its impact on gender participation in engineering education. He is a Research Scientist and Lecturer in the School of Engineering at Stanford University and teaches the course ME310x Product Management and ME305 Statistics for Design Researchers.

Mark has extensive background in consumer products management, having managed more than 50 consumer driven businesses over a 25-year career with The Procter & Gamble Company. In 2005, he joined Intuit, Inc. as Senior Vice President and Chief Marketing Officer and initiated a number of consumer package goods marketing best practices, introduced the use of competitive response modeling and "on-the-fly" A/B testing program to qualify software improvements.

Mark is the Co-Founder and Managing Director of One Page Solutions, a consulting firm that uses the OGSP® process to help technology and branded product clients develop better strategic plans. Mark is a member of The Band of Angels, Silicon Valley's oldest organization dedicated exclusively to funding seed stage start-ups. In addition, he serves on the board of several technology start-up companies.

### **Dr. Shannon Katherine Gilmartin, Stanford University**

Shannon K. Gilmartin, Ph.D., is a Senior Research Scholar at the Michelle R. Clayman Institute for Gender Research and Adjunct Professor in Mechanical Engineering at Stanford University. She is also Managing Director of SKG Analysis, a research consulting firm. Her expertise and interests focus on education and workforce development in engineering and science fields. Previous and current clients include the American Chemical Society, the Anita Borg Institute for Women and Technology, California Institute of Technology, the College of Natural Sciences and Mathematics at California State University Fullerton, the Office of the Vice Provost for Graduate Education at Stanford University, the School of Medicine at Stanford University, and the School of Fisheries and Ocean Sciences at the University of Alaska, Fairbanks.

### **Dr. Angela Harris, Stanford University**

Angela is currently a Fellow with the Thinking Matters program at Stanford University. Angela received her PhD in Stanford's Environmental Engineering and Science Program (Spring 2015). Angela completed her B.S. in Chemical Engineering at the Georgia Institute of Technology prior to coming to Stanford for her M.S. in Civil and Environmental Engineering.

Angela conducts research related to water, sanitation, and child health in developing countries. Angela has extensive experience in developing survey questionnaires and conducting structured observations at the household level as a part of research studies in Tanzania, Kenya, and Bangladesh. Alongside her work in environmental engineering, Angela also conducts research related to engineering education as part of DEL group. Currently her work related to education seeks to better understand student career choices and institutional support for students in career development and career preparation. She also works on better understanding undergraduate engineering student interests, behaviors, development, and career choices related to innovation and entrepreneurship.

### **Mrs. Beth Rieken, Stanford University**

Beth Rieken is a PhD Candidate at Stanford University in the Mechanical Engineering Department. Her work focuses on fostering mindful awareness, empathy and curiosity in engineering education. Beth completed a BS in Aerospace Engineering from the University of Virginia in 2010 and a MS in Mechanical Engineering from Stanford in 2012.

**Dr. Sheri Sheppard, Stanford University**

Sheri D. Sheppard, Ph.D., P.E., is professor of Mechanical Engineering at Stanford University. Besides teaching both undergraduate and graduate design and education related classes at Stanford University, she conducts research on engineering education and work-practices, and applied finite element analysis. From 1999-2008 she served as a Senior Scholar at the Carnegie Foundation for the Advancement of Teaching, leading the Foundation's engineering study (as reported in *Educating Engineers: Designing for the Future of the Field*). In addition, in 2011 Dr. Sheppard was named as co-PI of a national NSF innovation center (Epicenter), and leads an NSF program at Stanford on summer research experiences for high school teachers. Her industry experiences includes engineering positions at Detroit's "Big Three:" Ford Motor Company, General Motors Corporation, and Chrysler Corporation.

At Stanford she has served a chair of the faculty senate, and recently served as Associate Vice Provost for Graduate Education.

# **Innovation Self-Efficacy: A Very Brief Measure for Engineering Students**

## **Abstract**

When survey time is limited, education researchers may be faced with the choice of using an extremely brief measure of innovativeness or using no measure at all. To meet the need for a very brief measure, a 5-item innovation self-efficacy (ISE.5) scale was developed using the 19-item Dyer et al. Innovative Behavior Scale (IBS) as a starting point, adapted for undergraduate engineering students, and then condensed using confirmatory factor analysis.

The ISE.5 measures innovation self-efficacy as a unitary construct drawn from Dyer et al.'s five innovative behavior components (*Questioning, Observing, Experimenting, Networking Ideas* and *Associational Thinking*) and has good internal and external validity as well as good test-retest reliability. The ISE.5 (as a measure of innovation self-efficacy) is shown to be an important mediator between innovation interests and a desire to pursue innovative work as a career post-graduation. This mediator relationship is consistent among important sub-populations of engineering students such as females, underrepresented minorities and first generation college students. While not a substitute for a full multi-factor innovation assessment tool, the ISE.5 can serve as an important indicator of innovation self-efficacy among an undergraduate engineering student population.

## **1.0 Introduction**

In recent years, there has been increasing national and international attention directed toward promoting both innovation and its practical companion, entrepreneurship among engineering students. University campus-level programs such as VentureWell (2017), the Kern Entrepreneurship Education Network (2017) and UnternehmerTUM in Munich, Germany (2017) are actively involved in promoting innovation and entrepreneurship among engineering students and faculty. In addition, the Nation Science Foundation has made significant investments in the study and implementation of innovation and entrepreneurship through programs like Lean Launch Pad (2017), I-Corps (2017) and Epicenter at Stanford University (2017).

A major objective of the Epicenter program was to conduct research on innovation and entrepreneurship among United States engineering students. Part of this research involves a longitudinal survey, referred to as the Engineering Majors Survey (EMS), that aims to understand how engineering students make career choices that involve innovative work. An important measure within this research is an engineering student's confidence in their ability to be innovative, which we refer to as *innovation self-efficacy*. The first challenge in developing this measure is to define innovation in a way that is relevant to the process of engineering students making career choices, then develop a measurement scale that captures an engineering student's confidence in their ability to be innovative. This paper describes the development and validation process of an innovation self-efficacy scale, as part of the larger EMS study.

## 2.0 Background

### 2.1 Social Cognitive Career Theory and Innovation Self-Efficacy

The model/framework on which the EMS was based is Social Cognitive Career Theory (SCCT), and within the SCCT framework the concept of self-efficacy (specifically innovation self-efficacy) is a key concept.

An individual's vocational and career choice process has been an area of rigorous academic study for the past 70 years. Perhaps the first model of career choice to emerge was that of John Holland who posited that occupational satisfaction was a function of the match between an individual's "personality" and "vocation characteristics" (Nauta 2010). For example, in Holland's work, an engineering career was for the Realistic individual (Holland code: R) who is described as "independent, stable, persistent, practical, no-nonsense, down-to-earth" (Gottfredson and Holland 1996). Again, per Holland, the Realistic individual prefers "things rather than ideas or people, being outdoors, using tools, operating machines, and working with their hands" and would be happiest in work environments that had these characteristics.

As interesting as these descriptions are, they do little to help understand how background and academic learning experiences help shape career choice. In the early 1990's Robert Lent proposed a model of career choice called Social Cognitive Career Theory (SCCT, see Figure 1) that provided a framework for understanding, explaining, and predicting the processes through which people develop occupational choice (Lent, Brown, and Hackett 1994; Lent and Brown 2006). The SCCT model has as proven to be useful in predicting career choice among post-secondary students, particularly engineering students (Lent et al. 2005, 2007; Chubin et al. 2008) which makes it relevant for this study.

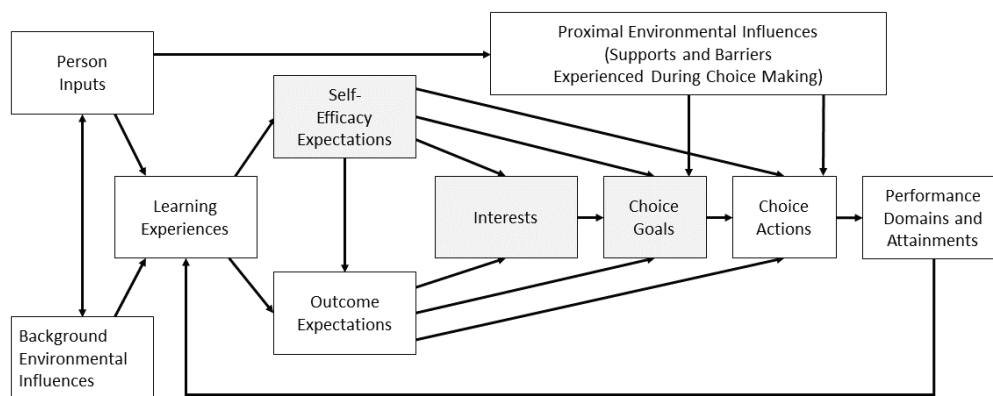


Figure 1- Lent's (1994, 2006) Social Cognitive Career Theory (SCCT) model. Bold nodes are included in this study.

The SCCT posits that vocational or career goals are a function of several social-cognitive variables, such as self-efficacy, outcome expectations, person inputs, background and environmental influences, and interests. Essentially, person inputs, background influences and learning experiences combine to predict self-efficacy and career outcome expectations. These, in

turn, predict career interests and ultimately career choice. The SCCT model has also been shown to reliably predict the Holland occupational themes (Sheu et al. 2010). An important element of the SCCT model is the distinction between innovative behaviors and innovation self-efficacy, which is discussed in detail in the following section.

## 2.2 Innovation Behaviors versus Innovation Self-Efficacy

Albert Bandura's concept of perceived self-efficacy is an important predictor of both interests and career choice. Bandura defines perceived self-efficacy as the extent or strength of one's belief in one's own ability to complete tasks and reach goals (Bandura 1977, 1997).

In Bandura's model (see Figure 2), efficacy expectations moderate behavior, and in turn, behavior is moderated by one's expectations of an outcome leading to action toward an outcome. Bandura characterizes perceived self-efficacy as agentic (Bandura 2001) - the intention to make things happen by one's action makes it particularly relevant in the pursuit of career goals. Bandura also asserts that self-efficacy beliefs can vary depending on situational considerations, such as within or outside of a domain of expertise and the circumstances surrounding the occurrence of behavior (Bandura 1982).

It is important to note that Bandura conceptualizes self-efficacy as a precursor to behavior, making a self-efficacy measure perhaps more meaningful than simply agreement to a list of proposed behaviors. This is an important distinction for the study of students and young professionals who often lack the life experiences that allow them to agree with a list of behaviors.

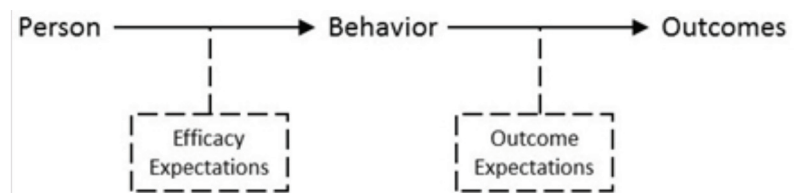


Figure 2- Bandura's (1977, 1994) model of self-efficacy

Bandura provides specific advice on the development of self-efficacy measures. (Bandura 2006) He states that "scales of perceived efficacy must be tailored to the particular domain of functioning that is the object of interest" (p 308), meaning that innovation self-efficacy scale items must be relevant to the work of engineering students. In the construction of self-efficacy scales Bandura recommends that "items should be phrased in terms of *can do* rather than *will do*. Can is a judgment of capability; will is a statement of intention. Perceived self-efficacy is a major determinant of intention, but the two constructs are conceptually and empirically separable" (p. 308). For the purposes of the ISE scale "*can do*" is interpreted a "*confidence in your ability to do*." Bandura also recommends that self-efficacy scales "be tailored to activity domains and assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain" (p. 310), which speaks to the need for a multi-faceted, rather than a unitary measure of innovation. This multifaceted measurement of self-efficacy is a "correlative process,"

per Bandura and valid and reliable self-efficacy scales should have a strong ( $>.80$ ) Cronbach alpha score.

## 2.3 Measuring Innovation Capability

The measurement of innovation, as a behavior distinct from creativity, began in earnest during the 1970's mostly as workplace organizations became interested in developing employee value creation capability. These early measurement techniques were centered on the notion that innovative behavior meant innovation, and these scales attempted to define innovative behaviors within a specific context or domain. These are known as behavior-based measures of innovation (see Table 1).

*Table 1. Selected Innovative Behavior Measurement Scales*

Author	Year	Scale Name	Constructs	Items
<b>Measures of Behavior</b>				
Jackson	1976	JPI: Innovation Subscale	1	20
Kirton	1976	KAI: Adaption-Innovation Inventory	2	32
Scott & Bruce	1994	IBM: Innovative Behavior Measure	1	6
Kleysen & Street	2001	IIB: Measure of Individual Innovative Behavior	1	14
Dyer et al.	2008	IBS: Innovative Behaviors Scale	4	19
Ferguson et al.	2016	ABAKAS: Assessment of Behaviors, Attributes, Knowledge, Attitudes, and Skills	23	82
<b>Measures of Self-Efficacy</b>				
Gerber et al.	2012	ISE: Innovation Self-Efficacy	13	39

Jackson was one of the first to develop a scale to measure innovation as a distinct paradigm from creativity. The Jackson Personality Inventory (Jackson 1976) defines innovation as a unitary construct that is an aspect of personality and a facet of analytical or cognitive skill. The JPI-Innovation subscale consists of 20-items (10 reversed), statements of innovative behavior, with agreement marked as true/false answers.

Kirton describes a cognitive style for creativity and problem solving which is a single, bipolar construct: on one pole are adapters, who solve problems within existing frames of perception by doing things better, and on the opposite pole are innovators, who restructure or reorganize the frames of perception leading to discontinuous or disruptive solutions. The Kirton Adaption-Innovation Inventory (Kirton 1976, 2003; Jablowski and Kirton 2009) is a 32-item (11 reversed) scale which presents specific characteristics, then asks respondents to rate the difficulty of accomplishing this characteristic. Research comparing the JPI-Innovation and KAI scales (Goldsmith 1986) conducted among college students found limited convergent validity between the two scales and, not surprisingly concluded that “a distinct construct called ‘innovativeness’ is still open to doubt” (p. 87).

Scott and Bruce (1994) were among the first to describe innovative behavior as a result of precedent behaviors such as leadership, individual problem-solving style, and work group relations. Influenced by the work of Kanter (1983; 1988), Scott & Bruce defined innovation as a unitary construct (meaning innovativeness was reduced to one measure with no sub-scales) and a



dependent variable that was impacted by a series of independent variables such as leadership dynamics, team dynamics, personal problem solving styles and the psychological climate surrounding the individual. To test this hypothesis, they developed an Innovative Behavior Measure (IBM) consisting of 6-items, describing innovative behaviors and they reported strong internal consistency ( $\alpha = .89$ ) for this measure. In the end, they found only limited support for their model of determinant innovative behavior, perhaps because their IBM may not have been a good predictor of actual innovative behavior. To confirm the validity of their IBM, they obtained “an objective measure of each respondent’s innovative history from the organization’s archives” and compared it to “the supervisor’s rating of innovative behavior” and found only a .33 ( $p < .001$ ) correlation.

By the early 2000’s there was a growing sense that innovation may not be a unitary construct, but rather a multi-faceted construct of unknown complexity. Business school professors Kleysen and Street (2001) conducted an extensive literature review on innovation, collecting 289 descriptions of innovative behavior and hypothesizing a five-construct model to describe innovative behavior. Structural equation modeling (SEM) was used on a sample of 225 employees from nine different organization and they found “a relatively poor fit between the hypothesized factor structure and respondents’ job behaviors.” They did find support for a single construct factor (14 items) that did successfully predict innovative job behavior. They conclude that a limitation of the research was the wide spectrum of organizations studied (e.g., manufacturing, consulting, public utility and an elementary school) may indicate that innovation is both multi-faceted and domain specific.

In 2008, Dyer, Gregersen and Christensen (2008) take an entirely different approach to measuring innovation, basing their scale on entrepreneurial exemplars. They began by interviewing 25 exemplar entrepreneurs such as Pierre Omidyar (eBay), Jeff Bezos (Amazon.com), Herb Kelleher (Southwest), and Scott Cook (Intuit) as well as 25 senior executives at large companies, then using the case study technique (Eisenhardt 1989) identified five constructs of innovative entrepreneurial behavior – questioning, observing, experimenting, idea networking and associational thinking. Selecting four of these behavioral constructs (questioning, observing, experimenting and idea networking) they developed 19-items (4-6 per construct) to define each construct.

This Innovative Behavior Scale (IBS) was tested with 382 managers and executives attending executive programs and executive MBA programs at three well-known business schools and a resulting factor analysis confirmed the underlying construct structure. To validate the scale, Dyer et al. returned to the original entrepreneurial exemplars, administered the scale and then compared the results to a sample of over five thousand executives and innovators in their database (2011) to confirm that there was a significant difference in behavior between innovative and non-innovative managers and executives. This work has resulted in a popular book, *The Innovator’s DNA: Mastering the Five Skills of Disruptive Innovators*, (2011) and website (2016) where managers and executives can take a version of the IBS to measure their own innovative behavior. A version of the IBS has also been used by Fila et al. (2015) to explore the similarities and differences in innovation discovery behaviors between student and working engineers and by Hess et al. (2016) to investigate empathic and innovative tendencies among engineering students.

Perhaps the most comprehensive work on engineering innovativeness to date has been conducted by the research team of Ferguson, Jablokow, Ohland, Purzer, and Menold (2016) who have developed and validated the “Assessment of Behaviors, Attributes, Knowledge, Attitudes, and Skills” (ABAKAS) scale. Ferguson et al.’s earlier conceptual work identified engineering innovative skills as a bridge between creative skills and entrepreneurial skills (Ferguson et al. 2013). In the development of their measurement scale, the research team conducted interviews with 45 peer-identified expert engineering innovators and through coding and analysis identified 23 key constructs that describe an engineering innovator (Ferguson 2013). A modified Delphi-technique was used involving 150 expert engineering innovators to define the construct areas and develop 82-items that describe behaviors within each construct. The resulting scale has been tested with both engineering students and engineers in the workplace and is considered both valid and reliable (see Ferguson et al. 2017a; Ferguson et al. 2017b).

In a departure from behavior-based measures of innovation, Gerber, Martin, Kramer, Braunstein, and Carberry (2012) were the first to investigate an innovation scale based on self-efficacy measures and tailored for engineering students. Their literature review of innovative task-related skills, behaviors or attitudes revealed 38 indicators that could be “learned or cultivate in an innovator.” Testing among academics and practitioners reduced the indicators to 25 and a list of 79-items were developed to describe these indicators. A pilot survey was administered to 62 engineering students at a large state university and respondents were asked to rate their degree of confidence in their ability to do each of the 79 tasks. Factor analysis revealed that the 79-items clustered into 13 indicators or constructs, each with 3-7 task-specific self-efficacy items. While this measure satisfied our criteria of measuring innovativeness through self-efficacy, the overall length (number of items) was too large for the framework of the Engineering Majors Survey.

## **2.4 Long-Form versus Short-Form Measures**

As the studies above show, there are several high-quality, valid, and reliable scales to measure engineering innovativeness, particularly among engineering students. It is also clear that more recent research conceptualizes “innovation” as a multi-faceted construct, involving between 5 and 23 subscales, in turn leading to survey scales with 19 to 82 items. The downside is that these scales tend to be long, creating “survey fatigue” problems, particularly when combined with other scales or items of interest to the researcher’s study area.

Ideally, researchers would have sufficient time and resources to deploy a well-established, multi-construct, multi-item scales, taking full advantage of their superior content validity and reliability. Unfortunately, many situations are not “ideal” and researchers are often faced with the uncomfortable choice of using an extremely brief scale or using no scale at all. A good example of this trade-off is in the area of personality research, where the “gold standard” scale is Costa and McCrae’s (1992) 240-item NEO Personality Inventory, Revised (NEO-PI-R), which measures five domain constructs of personality with six sub-scales for each construct. On average, the NEO-PI-R takes about 45 minutes to complete. While several briefer versions of the NEO-PI-R have been developed (John, Donahue, and Kentle 1991), they typically involve 40-50 items – better, but still not “short.”



To address the need for a truly brief measure, (Gosling, Rentfrow, and Swann 2003) have developed the Ten-Item Personality Indicator (TIPI) scale and have demonstrated adequate levels convergent validity and test-retest reliability with the NEO-PI-R. Thus, the TIPI has become a popular tool for brief assessment of personality dimensions typical within the context of larger studies where having a personality gauge may be a helpful diagnostic indicator.

### 3.0 Building on Prior Innovation Measures: Adapting the Dyer Innovative Behavior Scale

For the purposes of this paper, we have adopted Farr and West's (Farr and Ford 1990) definition of innovation as *the intentional introduction within one's work role of new and useful ideas, processes, products or services*. This definition places emphasis on both "new," linking innovation to creativity, and "useful," linking the outcome of innovation to benefit the person or organization. More recently, Ferguson and Ohland (2012) describe innovation skills as a bridge between creative skills and entrepreneurial skills.

The Dyer et al. model of innovation and their Innovative Behaviors Scale (IBS) were well-suited for the purposes of the Engineering Majors Survey. The IBS was developed through a lens of entrepreneurship, aligning with the work of Ferguson and Ohland, and linking to a specific career path. It is true that only a small fraction of engineering students are interested in entrepreneurship – either commercial or social (Lintl et al. 2015) – but the skills of entrepreneurship are broadly taught on engineering campuses (e.g., Duval-Couetil 2013) and these skills often transfer to work in larger organizations (Duval-Couetil, Reed-Rhoads, and Haghighi 2012) by means of "intrapreneurship" (see Antoncic and Hisrich 2003). Second, the Dyer et al. model is multi-faceted, including five constructs, which is consistent with the current thinking about the measurement of innovation. Finally, the IBS items, stated as behaviors, seemed readily adaptable to student-oriented self-efficacy statements.

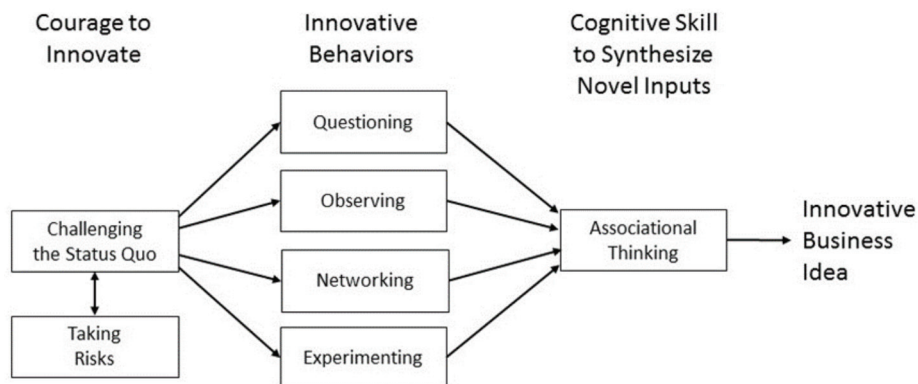


Figure 3 - Dyer et al. (2008, 2011) *The Innovator's DNA Model for Generating Innovative Business Ideas*

Dyer et al. conceptualize successful entrepreneurship as the ability to generate "innovative business ideas." (See Figure 3) To accomplish this, the successful entrepreneur must have the "courage to innovate," which combines with "innovative behaviors" and "cognitive skill to synthesize novel inputs" to generate innovative ideas. The 19-item IBS only measures the four "innovative behaviors" of questioning, observing, idea networking and experimenting.

The challenge of adapting Dyer's specific IBS items was two-fold: 1) the Dyer et al. instrument measures a set of innovative behavioral patterns are described in language that is associated with the workplace and not an undergraduate environment, and 2) these behavioral patterns are measured on an agree-disagree scale and are not expressed in self-efficacy terms. With Dyer's permission, each of the original IBS behavioral items were restated in "undergraduate engineering student language" with the intent of retaining as much of the original meaning as possible while expressing the behavior in a way that was relevant to engineering students. The revised statements were reviewed by a panel of current undergraduate engineering students and the language was discussed and adjusted. To compensate for a lack of an item describing "associational thinking" in the original Dyer scale, two additional statements were developed to describe this construct.

Finally, to convert the modified behavioral statements from an agree-disagree scale into a self-efficacy measure, the scale instructions were adjusted to reflect a self-efficacy intent (*"Please think about how confident you are in your ability to do these activities"*). A comparison of the original Dyer et al. IBS behavioral items and the restated ISE.5 self-efficacy items is shown in Appendix A.

## **4.0 Methods**

The validity and reliability of the ISE.5 measure was confirmed through three studies. Study 1 outlines the process of evolving the Dyer et al. scale into a very short measure of innovation self-efficacy for engineering students. Study 2 confirms the temporal stability of this scale through a test-retest analysis. Study 3 examines the external reliability of this innovation self-efficacy scale in the mediation of the relationship between innovation interests and the translation of those interests into a desire to pursue innovative career work. This process has been informed by the *Standards for Educational and Psychological Testing* (2014) that requires establishing evidence from multiple sources for the internal and external validity and reliability of any measurement scale. Consistent with these standards, the ISE.5 scale is only intended to measure innovation self-efficacy among United States undergraduate engineering students, and any use beyond this group requires additional validity and reliability testing.

## **5.0 Results**

### **5.1 Study 1 – Scale Construction**

The objective of Study 1 was to gather engineering student data on the adapted Dyer et al. IBS items and to conduct a confirmatory factor analysis to determine if it was possible to reduce the number of items while retaining the measurement capability of the original scale.

#### **Sample Characteristics**

The modified Dyer et al. items (19) plus two associational thinking items (total 21-items) were tested among a group of sophomores and junior ( $\bar{x}$  19.4 years) engineering students as part of an introduction to solid mechanics class at a large Midwestern state university. The sample totaled

334 respondents,<sup>1</sup> with 25% female, 8% underrepresented minorities and 20% first generation college students.<sup>2</sup> Respondents were shown the list of activity items (randomly presented) and asked rate their confidence-level of their ability to do each activity on a 5-point scale from Not Confident (1) to Extremely Confident (5).

## Descriptives

Respondents reported the highest level of innovation self-efficacy for the Experimenting component ( $\bar{x}$  3.62,  $\sigma$  .74), with the single highest rated item being (E.3) “*Be adventurous and seek out new experiences*” ( $\bar{x}$  3.79,  $\sigma$  .92), as shown in Appendix B. The lowest rated components were Idea Networking ( $\bar{x}$  3.27,  $\sigma$  .81) and Questioning ( $\bar{x}$  3.28,  $\sigma$  .73). The difference in mean scores between the highest rated and the lowest rated component was significant ( $\Delta \bar{x}$  .34, Cohen’s  $d$  .45), suggesting that the respondents were making real choices between the elements. The four Dyer et al. components (questioning, observing, experimenting, idea networking) showed acceptable internal validity (all  $\alpha > .80$ ) and the responses for each item were normally distributed.

## Confirmatory Factor Analysis

The objective of the confirmatory factor analysis is three-fold: 1) insure that the adapted Dyer et al. items approximate the structure of the original Dyer et al. items, 2) to confirm that the addition of “associational thinking” does not change the predictive ability of the overall model, and 3) to explore if a reduced number of items in the ISE.5 predicts the total number of adapted Dyer et al. items.

A four-factor confirmatory factor analysis was done with adapted Dyer et al. items to confirm the four-factor structure identified in the original Dyer et al. research. Next, the two Association Thinking items (A.1 and A.2) were added to the data set and a five-factor confirmatory factor analysis was done to confirm that Associational Thinking was a separate factor. The factor analysis was done using an oblique (Promax) rotation with a .50 factor loading cut-off. Factor loadings, alpha values, eigenvalues and cumulative variance is shown in Table 2.

The analysis supports a four-factor solution for the original Dyer et al. items and a five-factor solution with the addition of the Associational Thinking items. In the four-factor solution, there are many similarities with Dyer et al.’s results. Experimenting is the most significant factor in both data sets followed by Questioning. In Dyer et al.’s data the four-factor solution explained about 56% of the variance versus 54% in this data set. In terms of model fit, Dyer et al. reported a Root Mean Square Error of Approximation (RMSEA) of .14 and a Standardized Root Mean

---

<sup>1</sup> The original sample of 334 respondents contained 97.3% complete data. It was determined that the missing data was missing completely at random (MCAR) and multivariate imputation by chained equations (MICE) was used with predictive mean matching (PMM) and 5-iterations to complete the data set. (Manly and Wells 2015; van Buuren and Groothuis-Oudshoorn 2011)

<sup>2</sup> For the purposes of Study 1, Study 2 and Study 3, underrepresented minority (URM) is defined as any respondent who indicated a Latino/a, African American, Native American or Pacific Islander ethnicity. First Generation College (FGC) is defined as any respondent where both the mother/female guardian and father/male guardian had less post-secondary education than an Associate degree. This is regarded as a broader definition of FGC students. (Choy 2001; Auclair et al. 2008; Toutkoushian, Stollberg, and Slaton 2015)

Square Residual (SRMS) of .16 while this model had a RMSEA of .08 and a SRMS of .06, indicating a better fit for this model (RMSEA and SMRS values  $\leq .08$  are considered a good fit - see Schreiber et al. 2006; Hu and Bentler 1999). In this model, there is a concern over the eigenvalues of Factors 4 and 5 which are both below the standard of 1.0 (Dyer et al.'s eigenvalues for all factors were above 1.0), indicating that in this data set these factors may not be significant and that a fewer factor solution may be appropriate. Dyer et al. reported the same concern but decided to remain with a four-factor solution "to maintain consistency with the innovative entrepreneur behaviors identified the qualitative study." (p. 331)

Table 2- Principal Factor Analysis of the Dyer et al. IBS items

Component/Item	Four-Factor Loadings				Five-Factor Loadings				
	1	2	3	4	1	2	3	4	5
<b>Experimenting</b>									
E.1 Experiment as a way to understand how things work	.99				.83				
E.2 Experiment to create new ways of doing things	.73				.66				
E.3 Be adventurous and seek out new experiences					.53				
E.4 Actively search for new ideas through experimenting	.79				.69				
E.5 Take things apart to see how they work	.77				.65				
<b>Questioning</b>									
Q.1 Ask a lot of questions		.96					.97		
Q.2 Ask the right questions to get to the root of a problem									.68
Q.3 Ask more questions than my classmates		.87					.77		
Q.4 Ask the kind questions that change the way others think about a problem									
Q.5 Ask questions that challenge fundamental assumptions									
Q.6 Ask questions to understand why projects or designs underperform									
<b>Idea Networking</b>									
I.1 Build a network of people for new perspective, refine my ideas			.82			.79			
I.2 Seek advice of students and faculty to test ideas									
I.3 Reach out outside of my major to spark ideas for a new product or service									
I.4 Build a large network of contacts, get ideas for new products or services			1.00			1.00			
<b>Observing</b>									
O.1 Think of new ideas by watching people interact with products and services				.73					.68
O.2 Generate new ideas by observing the world				.66					.69
O.3 Observe how people use products and services to help me get new ideas				.74					.74
O.4 Pay attention to everyday experiences as a way to get new ideas									
<b>Associational Thinking</b>									
A.1 Connect concepts and ideas that appear, at first glance, to be unconnected									.70
A.2 Connect ideas from different and diverse areas									.60
Eigenvalue	8.57	1.77	1.23	.82	9.52	1.80	1.24	.84	.80
Cumulative Variance	.20	.32	.44	.54	.13	.23	.33	.42	.51

The factor loading cutoff point was .50. Items **shaded** are used in the ISE.5 scale

We were interested in building upon the adapted Dyer et al. 19-item, four-factor model and exploring the effect of adding items related to "associational thinking," an important skill in the overall definition of innovative entrepreneurial behavior. Two-items were added to the analysis (A.1 *Connect concepts and ideas that appear, at first glance, to be unconnected* and A.2 *Connect ideas from different and diverse areas*) and a five-factor confirmatory factor analysis was conducted on these now 21-items. The results show that the associational thinking items do load onto a fifth factor, along with Q.2 *Ask the right questions to get to the root of a problem*. Model variance remains the same (51% versus 54%) while RMSEA (.08) and SRMS (.06) remained the same as the four-factor model. From this, we concluded that the addition of the Associational Thinking items improves the conceptual fit with Dyer et al.'s model while maintaining acceptable statistical fit.

## Selecting the Items – ISE.5 Scale

The selection of the individual items that make up the ISE.5 was guided by the five-factor confirmatory factor analysis (Table 2). Three-items, each representing a factor were obvious choices: Factor 1 - Experimenting E.1 (factor loading .83), Factor 2 – Idea Networking I.4 (factor loading 1.00) and Factor 3 – Questioning Q.1 (factor loading .97). Factor 4 had three items with very similar loadings, so we chose Observing Q.2 (*Generate new ideas by observing the world* - factor loading .69) because it appeared to be more applicable to a more general undergraduate perspective than the other items that referenced “products and services.” Finally, Factor 5 - Associational Thinking also had three items with very similar loadings, so we chose A.1 (*Connect concepts and ideas that appear, at first glance, to be unconnected* - factor loading .70) because it appeared to be more descriptive of the innovative entrepreneurial behavior described by Dyer et al.

These five items (that comprise ISE.5) have a strong and significant correlation with each other and the four Dyer et al. components (see Table 3). The individual ISE.5 items each have a strong and significant correlation (.75 to .85) with the components from which they are drawn. Importantly, an ISE measure based on four-items has a .93 correlation with the full 19-items IBS scale, and the five-item ISE.5 has a .94 correlation with the IBS scale.

Table 3- Pearson *r* Correlation between the Dyer et al. Constructs and ISE.5 Items

Dyer et al. Components	ISE.5 Items						
	Q.1	O.2	E.1	I.4	A.1	4i	5i
Questioning (6-items)	.75	.62	.49	.45	.54	.83	.83
Observing (4-items)	.33	.85	.61	.43	.62	.78	.81
Experimenting (5-items)	.33	.66	.83	.40	.59	.77	.79
Idea Networking (4-items)	.44	.43	.42	.83	.41	.76	.74
IBS (19-items)	.57	.75	.69	.61	.64	.93	.94
Four Item ISE.5 (4i)	.68	.74	.72	.67	.56	--	.98
Five Item ISE.5 (5i)	.59	.77	.76	.61	.72	.98	--

n = 334, all correlations are significant at  $p < .000$

Regression analysis confirms that the both the four- and five-item ISE scales is an effective predictor of the adapted Dyer et al. 19-items (see Table 4). The four-item ISE (called ISE.4 in Table 4) explains 87% of the variance in the full IBS, while the five-item ISE.5 explains 88% of the variance. The addition of the Associational Thinking item, while the weakest predicting variable ( $\beta .15$ ,  $t = 6.31$ ,  $p < .000$ ), provides a statistically significant improvement in fit (adjusted  $r^2$  from .87 to .88,  $F 39.77$ ,  $p < .000$ ). This may be because the factor loading of the Associational Thinking item (A.1) is statistically similar the Questioning – Q.2 item (see Table 3) and reinforces both the Questioning and Associational Thinking components.

Table 4- Regression Analysis Summary for ISE.5 Items Predicting the 19-Item Innovative Behavior Scale (IBS)

Item	Four-Item ISE.4				Five-Item ISE.5			
	$\beta$	$SE$	t	p	$\beta$	$SE$	t	p
(Intercept)	.00	.02	0.00	--	.00	.02	0.00	--
Q.1	.28	.02	13.15	.000	.28	.02	13.76	.000
O.2	.40	.02	16.31	.000	.35	.02	14.22	.000
E.1	.31	.02	12.89	.000	.26	.02	10.85	.000
I.4	.32	.02	15.03	.000	.31	.02	15.10	.000
A.1					.15	.02	6.31	.000
Adjusted $r^2$	.87				.88			

n = 334,  $\beta$  and  $SE$  - standardized

The third objective of the confirmatory factor analysis and ISE.5 item selection was to determine if the individual items selected for the ISE.5 could singularly represent the component from which they are drawn. A comparison of means, SD, difference measure by Cohen's d and Pearson r-squared between the Dyer et al. components and the individual items of the ISE.5 are shown in Table 5.

While the individual ISE.5 items have comparable means to the multi-item components, the amount of variance explained by the single variable falls below a meaningful threshold of validity, suggesting that the ISE.5 is best used as a unitary measure representing the totality of the adapted Dyer et al. items and not as an indicator of the individual components that make up the Dyer et al.'s Innovation Behavior Scale. The amount of variance (as measured by Pearson's  $r$ -squared) explained by the individual items ranges from a low of 56% for Questioning to a high of 72% for Observing, and even at the high end of variance explanation, it still falls below the 80%+ threshold commonly used to establish inter-item validity.

Table 5 - Comparison of Means, SD, Cohen's d and Pearson r-squared between the Dyer et al. Components and the Individual Items of the ISE.5

Dyer et al. Component	$\bar{x}$	$\sigma$	ISE.5 Items	$\bar{x}$	$\sigma$	d	$r^2$
Questioning (6-items)	3.28	.73	Q.1 Ask a lot of questions	3.35	1.10	.07	.56
Observing (4-items)	3.54	.77	O.2 Generate new ideas by observing the world	3.61	.93	.07	.72
Experimenting (5-items)	3.62	.74	E.1 Experiment as a way to understand how things work	3.64	.93	.02	.69
Idea Networking (4-items)	3.27	.81	I.4 Build a large network of contacts with whom I can interact with to get ideas for new products or services	3.20	1.02	.07	.70
Associational Thinking	--	--	A.1 Connect concepts and ideas that appear, at first glance, to be unconnected	3.40	.87	--	--
Scale Mean (19-items)	3.42	.64	Scale Mean (5-items)	3.44	.67	.03	.88

n = 334, d = Cohen's d comparative mean effect size (no difference < .20),  $r^2$  - Pearson r squared



## 5.2 Study 2 - ISE.5 Scale Test-Retest Reliability

The objective of Study 2 was to confirm the temporal stability of the five-item ISE.5 scale through test-retest reliability.

### Sample Characteristics

The ISE.5 was tested among a group of sophomores and junior ( $\bar{x}$  20.5 years) engineering students as part of an introduction to solid mechanics class at a large state university. The ISE.5 was administered twice (T1 and T2), 14.1 days apart. The students that completed both the first and second surveys totaled 110 respondents,<sup>3</sup> with 20% female, 40% underrepresented minority and 53% first generation college respondents. Respondents were shown the ISE.5 items (randomly presented) and asked to rate their confidence-level in their ability to do each activity on a scale from Not Confident (1) to Extremely Confident (5).

### Affect as a Covariant

In addition, respondents were assessed on their affect or “mood” at both times they were taking the ISE.5 scale to serve as a covariant measure to help explain any changes in pre-post results. The use of state-affect as a covariant control on self-efficacy results is relatively common in social science research, and novel in engineering education research. Affect has long been associated with an impact on self-efficacy, (see Kavanagh and Bower 1985; Baron 1990; Thatcher and Perrew 2002; Vancouver et al. 2002) with positive affect tending to increase self-efficacy and negative affect decreasing self-efficacy. In the moment affect was measured (“*how are you feeling right now?*”) using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, and Tellegen 1988), specifically using a short-form, 10-item version (Thompson 2007): the 10-item PANAS is comprised of 5 positive affect (PA) items and 5 negative affect (NA) items (randomly presented) rated on a scale of (1) *very slightly or not at all* to (5) *very much*.

The mean score for both the positive affect items and negative affect items was calculated and then the negative affect mean was subtracted from the positive affect mean (PA-NA) resulting in a net affect measure with a positive value indicating net positive affect and a negative value indicating net negative affect. For example, at T1 the mean net affect score was +1.20 with a range from -3.40 to +3.80 for the sample. (see Table 6)

This net affect measure was collected for each respondent both times they completed the ISE.5 (T1 and T2) and the first net affect measure was subtracted from the second net affect measure (T2 – T1) to obtain a net change in affect measure. This net change in affect was used as a covariant variable to help explain changes in the ISE.5 score between the first and second administration.

---

<sup>3</sup> This sample was drawn from a class of 179 students and participation was voluntary and no compensation was provided. A total of 157 respondents completed the first survey and 119 completed the second survey, resulting in a net 110 respondents with both first and second survey data. Comparing these 110 respondents to the remaining 47 respondents who completed only the first survey showed no statistical differences in rate of gender, URM or first generation college participation or ISE.5 score. The resulting data set was 99.5% complete and it was determined that the missing data was missing completely at random (MCAR). Multivariate imputation by chained equations (MICE) was used with predictive mean matching (PMM) and 5-iterations to complete the data set.

## Descriptives and Correlation

Comparing results from T1 to T2 shows significant differences on several of the ISE.5 item ratings and for the ISE.5 in total – all in the positive direction. For example, items *O.2 Generate new ideas by observing the world* (+.30), *I.4 Build a large network of contacts with whom I can interact, to get ideas for new products or services* (+.37) and *A.1 Connect concepts and ideas that appear, at first glance, to be unconnected* (+.26) all showed small, positive and significant differences between T1 and T2. The 5-item ISE.5 (+.21) also showed a small, positive and significant difference between T1 and T2. Results comparing the mean scores for the ISE.5 items and total are shown in Table 6.

Table 6 - Item and Scale Means and SD from the ISE.5 Test-Retest Study

Item	Time 1 (T1)		Time 2 (T2)		T2 – T1		
	$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$	$\bar{x}$ diff	<i>d</i>	<i>r</i>
Q.1 Ask a lot of questions	3.25	1.14	3.36	1.01	+.11	.10	<b>.59</b>
O.2 Generate new ideas by observing the world	3.37	1.00	3.67	.90	<b>+.30</b>	<b>.31</b>	<b>.54</b>
E.1 Experiment as a way to understand how things work	3.67	.87	3.70	.92	+.03	.03	<b>.55</b>
I.4 Build a large network of contacts with whom I can interact, to get ideas for new products or services	2.95	1.08	3.32	1.06	<b>+.37</b>	<b>.34</b>	<b>.68</b>
A.1 Connect concepts and ideas that appear, at first glance, to be unconnected	3.09	.88	3.35	.90	<b>+.26</b>	<b>.29</b>	<b>.53</b>
ISE.5 (5-items)	3.27	.75	3.48	.76	<b>+.21</b>	<b>.28</b>	<b>.70</b>
Net Affect (PA-NA)	1.20	1.50	1.50	1.34	<b>+.30</b>	<b>.20</b>	<b>.65</b>

n = 110

*d* = Cohen's *d* effect size (BOLD, small difference .20 - .50), *r* = Pearson *r* correlation; all significant ( $p < .000$ )

Pearson *r* correlation between T1 and T2 for all items ranged from a low of .55 (for item A.1) to a high of .68 (for item I.4). The correlation between the 5-item ISE.5 from T1 to T2 was .70, which as a measure of test-retest reliability is considered “acceptable.” The threshold for acceptable test-retest reliability correlation varies by domain, with social science research accepting a .70 threshold, while the clinical research threshold is much higher at .95 (Nunnally and Bernstein 1994).

Table 7 - Hierarchical Regression Analysis Summary for Affect Variables Predicting ISE.5 at T1

Step and Predictor Variable	Model Fit			Difference Between Steps		
	$\beta$	<i>SE</i>	Adj <i>r</i>	$\Delta$ Adj <i>r</i>	F	<i>p</i>
<b>Step 1:</b>			.70		Base	Base
T2 ISE.5 Score	.70	.07				
<b>Step 2:</b>			.74	.04	13.84	.000
T2 ISE.5 Score	.54	.08				
Average Affect Score (T1 and T2)	.29	.08				
<b>Step 3:</b>			.76	.02	9.67	.000
T2 ISE.5 Score	.55	.08				
Average Affect Score (T1 and T2)	.26	.08				
Change in Affect Score (T2 – T1)	.20	.06				

n = 110, standardized  $\beta$  coefficient and *SE*, all predictor variables significant ( $p < .000$ )

The predictive relationship between T1 and T2 ISE.5 scores significantly improves when controlling for affect, as shown in Table 7. As expected, there is a significant .63 correlation ( $p < .000$ ) between average ISE.5 scores (average of T1 and T2) and the average net affect score – in general, higher net positive affect is associated with higher self-efficacy scores. The addition of average affect score to the predictive model (see Step 2 below) significantly improves model fit from .70 to .74 ( $F = 13.84, p < .000$ ) and the addition of change in affect score (see Step 3 below) for T1 to T2 again significantly improves adjusted  $r$  model fit to .76 ( $F = 9.67, p < .002$ ). At this higher level of model fit, test-retest reliability for the ISE.5 can be considered “good.”

### 5.3 Study 3 - ISE.5 Scale External Validity

The objective of Study 3 was to determine the external validity of the ISE.5. We define external validity as the influence of ISE.5 on other measures of innovation interest and the degree to which this relationship holds for important subsets of the overall sample population. According to the Lent SCCT Model (see Figure 1) innovation self-efficacy should influence both innovation interests and an individual’s choice to pursue innovative work as a career goal. To test this relationship, a mediation analysis of ISE.5 and its influence on other, related measures of innovation interest should serve as a measure of external validity.

### Sample Characteristics and Additional Scales

The five-item ISE.5 was included as part of the Engineering Majors Survey, (Stanford University 2016) to investigate how engineering students make innovative career choices. The national sample<sup>4</sup> of Junior, Senior and 5th Year engineering students totaled 5,819 respondents, with 30% female, 14% underrepresented minorities (URM) and 16% first generation college students (FGC). There were no statistically significant differences in the ISE.5 mean scale score between all respondents and important subsets such as females, males, underrepresented minorities and first generation students, as shown in Table 8.

*Table 8 - Comparison of Means, SD, Median and Skew between the All Respondent Sample and Important Subsets for the ISE.5 Scale*

Sample	n	ISE.5 Scale			
		$\bar{x}$	$\sigma$	Median	Skew
All Respondents	5,819	3.62	.74	3.60	-.33
Female	1,722	3.55	.74	3.60	-.32
Male	4,097	3.65	.73	3.60	-.34
Underrepresented Minority (URM)	807	3.64	.79	3.80	-.48
First Generation College (FGC)	932	3.58	.78	3.60	-.37

No significant difference in  $\bar{x}$  between sample groups as measured by effect size (Cohen’s  $d$ )

<sup>4</sup> The Engineering Majors Survey was distributed to a stratified selection of 27 engineering schools throughout the US representing over 30,000 engineering students. In total, 7,197 responses were collected and after screening for Junior, Senior and 5<sup>th</sup> Year students and the cleaning of limited data responses, resulted in a 5,819 respondent analysis data set. The analysis data set contained 96.5% complete data. It was determined that the missing data was missing completely at random (MCAR) and multivariate imputation by chained equations (MICE) was used with predictive mean matching (PMM) and 5-iterations to complete the data set. (Gilmartin et al. 2017)

In addition to the ISE.5, this survey also measured two interest scales of note: Innovation Interests (INI), and Career Goals: Innovative Work (CGIW).<sup>5</sup> The items that comprise these scales are shown in Appendix C and for context and more detail on the development of these items see the EMS Technical Report. (Gilmartin et al. 2017)

**Innovation Interests (INI)** – Lent and Brown (2006) describe “interests” as “people’s pattern of likes, dislikes, and indifferences regarding different activities” and are impacted by both by self-efficacy and outcome expectations (see Figure 1). INI contextualizes the practice of innovation behavior, integrating references to both Dyer et al.’s (2008) discovery-based behaviors and Kanter’s (1988) enumeration of innovation tasks. That is, INI, like ISE, measures respondents’ orientation to the discovery and idea generation aspects of innovation (aligning with Dyer), and unlike ISE, measures other aspects of the innovation process, namely coalition-building, idea realization, and transfer/diffusion (aligning with Kanter).

The first item in INI, “*experimenting in order to find new ideas*,” is designed to coordinate with a similarly worded item in ISE. The next three items are designed to coordinate with the post-idea-generation stages of innovation. “*Giving an elevator pitch or presentation*,” “*finding resources to bring new ideas to life*” and “*developing plans and schedules to implement new ideas*” link to the behaviors required to implement innovative ideas and are adapted from Duval-Couetil et al. (2012) There is also have a measure of interest in discovery-based scholarly innovation, “*conducting basic research on phenomena in order to create new knowledge*,” drawing from Eesley and Miller (2012) which add insight on possible academic career choice among engineers.

**Career Goals: Innovative Work (CGIW)** - CGIW is the primary outcome measure in the proposed basic SCCT model (see Figure 1) used for the Engineering Majors Survey. The six items that compose CGIW are based on Kanter (1988) and the adaptation of Kanter’s innovation tasks to individual-level behaviors in Scott and Bruce (Scott and Bruce 1994) and YES (Lerner and Damon 2011). Although previous studies did not show an exact mapping of each item to Kanter’s tasks, it is fair to assume that the first two items (“*searching out new technologies, processes, techniques, and/or product ideas*” and “*generating creative ideas*”) reflect Kanter’s “idea generation”, the third (“*promoting and championing ideas to others*”) reflects “coalition-building”, the fourth (“*developing adequate plans and schedules for the implementation of new ideas*”) reflects “idea realization”, and the fifth (“*selling a product or service in the marketplace*”) reflects both “idea realization” and “transfer/diffusion.”

We developed and added the sixth (“*selling a product or service in the marketplace*”) to further specify Kanter’s “transfer/diffusion” innovation task and reflect the necessity in the working world for generating revenue. As a single construct, CGIW measures one’s aspirations to be involved in multiple phases or facets of “innovative work” in their careers, (i.e., lower scores indicate low importance attributed to being involved in all, or nearly all, innovation tasks, and higher scores indicate high importance attributed to being involved in all, or nearly all, innovation tasks). These six items are measured on an importance scale to better approximate

---

<sup>5</sup> The scale range for selected items (ISE.5, INI, CGIW) was shifted from 0 to 4 to 1 to 5, to align with the scale range of Study 1 and Study 2.

“career goals” in SCCT, from “not important” (1) to “extremely important” (5) and had a sample mean ( $\bar{x}$ ) of 3.53 ( $\sigma$  .79) and a strong alpha ( $\alpha$  .85) indicating that these items form a unitary construct.

## Descriptives and Correlations

There are strong and significant correlations between the ISE.5, INI and CGIW scales, as shown in Table 9. Innovative interest (INI) and career goals: innovative work show a strong and significant correlation ( $r = .66$ ). However, the impact of ISE.5 on both INI and CGIW is less pronounced ( $r$  from .45 to .53) and this brings into question the external validity of the ISE.5 as a predictor of either innovative interest or career goals: innovative work.

Table 9 - ISE.5, INI and CGIW Scale Descriptives and Pearson  $r$  Correlations

	Scale	Descriptives			Pearson $r$	
		$\bar{x}$	$\sigma$	$\alpha$	1	2
1	ISE.5	3.62	.74	.78	--	
2	INI	3.53	.68	.80	.53	--
3	CGIW	3.53	.79	.85	.45	.66

$n = 5,819$ , all Pearson  $r$  correlations are significant ( $p < .000$ )

Lent’s SCCT model proposes that self-efficacy will have an impact on both interests and career choice (see Figure 1). This suggests that a respondent’s innovation self-efficacy (ISE.5) could mediate the relationship between innovation interests (INI) and the choice of career goals that include innovative work (CGIW). A mediation analysis, as defined by Baron and Kenny (1986) provides evidence of the external validity of the ISE.5 scale. An overview of this analysis is shown in Figure 4.

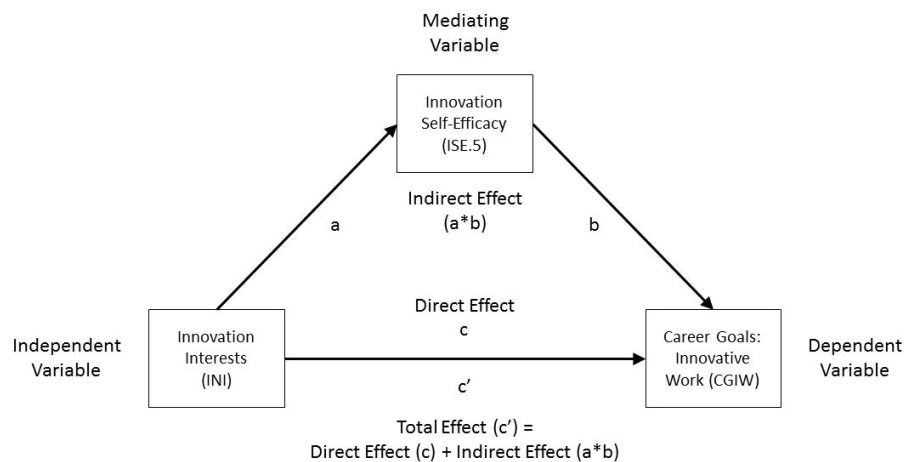


Figure 4 - Mediation analysis of the impact of ISE.5 on the relationship between INI and CGIW

For the full sample of respondents, the direct effect ( $c$ ) standardized  $\beta$  coefficient between Innovation Interests (INI) and Career Goals: Innovative Work (CGIW) is .58, as shown in Table 10. The total effect ( $c'$ ) which includes the mediating effect of innovation self-efficacy (ISE.5) is

.66, which is a significant difference as measured by the Sobel Test.<sup>6</sup> Results by sample subsets of all females (n = 1,722, Direct Effect  $c = .57$ , Indirect Effect  $c' = .64$ ) and all males (n = 4,097, Direct Effect  $c = .58$ , Indirect Effect  $c' = .66$ ) show that the ISE.5 has a significant, positive mediation effect on the relationship between a respondent's innovation interests and their choice to pursue innovative work as a career goal.

*Table 10 - Results of Mediation Analysis of the Impact of ISE.5 on the Relationship between INI and CGIW by Gender, Under Represented Minority and First Generation College Status*

Sample	n	Indirect Effect			Direct Effect	Total Effect	Sobel Test
		<i>a</i>	<i>b</i>	<i>a*b</i>	<i>c</i>	<i>c'</i>	<i>p</i>
All Respondents	5,819	.53	.14	.08	.58	.66	.000
Females	1,722	.52	.13	.07	.57	.64	.000
Males	4,097	.54	.15	.08	.58	.66	.000
Underrepresented Minority	807	.53	.11	.05	.63	.68	.000
First Generation College	932	.58	.10	.06	.60	.66	.000

Standardized *B* coefficients, all Sobel Test results are significant ( $p < .000$ )

While the direct effect between INI and CGIW was greater for underrepresented minorities ( $c = .63$ ) and first generation college students ( $c = .60$ ) than the overall sample, ISE.5 still had a significant, positive mediation effect (URM  $c' = .68$ , FGC  $c' = .66$ ). This indicates that ISE.5 has meaningful external validity as a measure of innovation self-efficacy.

## 5.4 Limitations

It seems clear from the current work on measuring innovative behavior that innovation self-efficacy is a multi-faceted construct. However, while the ISE.5 is formed from a multi-construct model, it is statistically most reliable measuring innovation as a unitary construct. The items within the ISE.5 correspond with the key components of Dyer et al.'s *Innovator's DNA* and do, in part, represent these components, but not to the level that would give confidence that they each provide a fair representation of the complete construct. This is the trade-off that comes with "short-form" scales; granularity is often sacrificed for the sake of brevity.

As Bandura counsels, to be effective, self-efficacy scales must "be tailored to activity domains and assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain" (Bandura 2006, 310) The ISE.5 is drawn from the "activity domain" of innovative entrepreneurship with its distinct links to commerce. There are many other domains and areas of expertise that link to innovation, such as creativity, design thinking or problem solving. It could be argued that the selection of innovative entrepreneurship as the inspiration for engineering innovation may be overly focused or even inappropriate given the very small number of engineers who become entrepreneurs.

The purpose of this scale, to measure innovation self-efficacy of undergraduate engineering students, is itself a limiting characteristic. It is very possible that a student's view of innovation

<sup>6</sup> The Sobel Test, described by Baron and Kenny (1986), is sufficient to detect up to small differences within a large (1,000 +) sample size. (MacKinnon et al. 2002)



and their confidence in their own innovative capabilities changes overtime as they accumulate experiences and grow in ability. For example, the ISE.5 item *“build a large network of contacts with whom I can interact with to get ideas for new products or services”* is the lowest rated capability among undergraduate students while *“experiment as a way to understand how things work”* is the highest rated capability. It is entirely possible that as engineering students grow in their domain skills and start to look toward employment these items might reverse their importance. The ISE.5 measure is only a snapshot view of a moment in time, measuring a momentary state rather than an enduring trait of innovation capability.

Finally, the focus on measuring self-efficacy rather than specific characteristics or behaviors may be limiting. Most agree that self-efficacy is a precursor to behavior, but it is still not actual behavior and behaviors can be qualified and measured. The growing interest in measuring innovation among undergraduate engineering students has led to some comprehensive efforts to measure innovative characteristics and behaviors. Most notable is ABAKAS (see Table 1), the scale developed by Ferguson and Jablonski et al. (Menold et al. 2016) that was developed by observing characteristics and behaviors of engineers in the workplace and assesses 23 components of innovative behavior via 82 items. It could prove over time that this scale has the highest external validity of any measurement of engineering innovativeness.

## **6.0 Conclusion and Implications**

This paper finds evidence to support the internal and external validity, reliability, and predictive utility of the very brief innovation self-efficacy scale (ISE.5) consisting of five items. Study 1 extracted the relevant five items from the Dyer et al. Innovative Behavior Scale through confirmatory factor analysis and showed strong the internal validity of this brief 5-item scale to duplicate results from the longer (19-item) Dyer et al. scale. The 5-item ISE.5 scale also improves the conceptual fit with the Dyer et al. innovation model by including “associational thinking” while maintaining overall statistical equivalence with the full Dyer et al. scale.

Study 2 confirmed the temporal stability of the five-item ISE.5 scale through test-retest reliability. The ISE.5 had strong and significant correlations after the 14-day test-retest period and regression results controlling for affect “in the moment,” accounted for over 76% of the test-retest variance. Study 3 confirmed a measure of external reliability by showing through mediation analysis that the ISE.5 construct has significant impact on the relationship between innovation interests and the career choice for innovative work.

The positive mediating effect of innovation self-efficacy on the relationship between innovation interests and the career choice of innovative work could have profound implications for today’s engineering curriculum. This suggests that to seek innovative career work requires a confidence in one’s innovative capability. It may be possible to use the individual items of the ISE.5 to inform engineering curriculum development, by asking curriculum and pedagogy-related questions such as *“how are we encouraging the asking of questions?”* or *“how does this build observation skills?”* or *“does this help the student connect ideas that do not seem connected?”* This has interesting implication of a range of topics from curriculum development to academic experiences and pathway to the definitions with ABET criteria A-K.

As it is likely that innovation self-efficacy develops over time through a variety of experiences in a variety of ways, it will be helpful to understand how the antecedents of innovation self-efficacy, (e.g., familial environment, high school and undergraduate academic and extracurricular experiences) form innovation self-efficacy. It is also important for the study of “innovativeness” among students, who often lack the life experience that would allow them to agree with a list of behaviors, to create self-efficacy measures based on perceived self-efficacy or the strength of their belief in their ability to complete a possible task or reach a potential goal. A valid and reliable innovation self-efficacy scale helps make this type of research more realistic.

Similarly, it would be interesting to understand how innovation self-efficacy predicts a choice of major or a specific career choice, down to the industry-level, with job characteristics and perhaps specific company. This might also lead to an investigation of how innovation self-efficacy changes over time, from an undergraduate engineering student, to an entry-level engineer to an engineering manager. Of course, the challenge is that innovation is both domain and context specific, so the ISE.5 scale may be the wrong tool to use for this process.

Finally, the understanding of innovation self-efficacy as a precursor to innovative behaviors has implications for measuring self-efficacy in other areas important to engineering education. For example, Natasha Mamaril, Ellen Usher, Caihong Li, Ross Economy, and Marian Kennedy (Mamaril et al. 2016) recently completed an excellent analysis of the many factors that make up engineering task self-efficacy. The resulting scale (3 components, 12-items) provides a concise measure and, perhaps, in combination with the ISE.5 offers a brief and powerful way to understand engineering students’ innovative behaviors and career choices.

## **7.0 Acknowledgements**

The EMS study was conducted with support from the National Center for Engineering Pathways to Innovation (Epicenter), a center funded by the National Science Foundation (grant number DUE-1125457) and directed by Stanford University and VentureWell, formerly the National Collegiate Inventors and Innovators Alliance (NCIIA). The EMS research continues with funding support from the National Science Foundation (grant number 1636442).

We would also like to thank Dr. Robert Witt of the University of Wisconsin-Madison and Dr. Robert Rice of the University of California-Merced for their support and access to their talented undergraduate engineering students for survey feedback. A special thanks to Dr. Jeffery Dyer who graciously agreed to let us both use and modify his Innovative Behavior Scale for the purposes of this project and Dr. Albert Bandura who provided advice and counsel on the adaption of behavior scale items to self-efficacy scale items. We also appreciate content and editing advice from Dr. Tua Björklund (Aalto University, Finland) as well as the members of Stanford University’s Designing Education Lab. Finally, a heart-felt thank you to the thousands of U.S. engineering students who have given their time and attention to this project.

## References

- Antoncic, B., and R.D. Hisrich. 2003. "Clarifying the Intrapreneurship Concept." *Journal of Small Business and Enterprise Development* 10 (1): 7–24.
- Auclair, R., P. Belanger, P. Doray, M. Gallien, A. Groleau, L. Mason, and P. Mercier. 2008. *Transitions: Research Paper 2 - First-Generation Students: A Promising Concept*. Number 39. Montreal, QC, Canada: The Canada Millennium Scholarship Foundation.
- Bandura, Albert. 1977. "Self-Efficacy: Toward a Unifying Theory of Behavioral Change." *Psychological Review* 84 (2): 191.
- . 1982. "Self-Efficacy Mechanism in Human Agency." *American Psychologist* 37 (2): 122.
- . 1997. *Self-Efficacy: The Exercise of Control*. 1st edition. New York: Worth Publishers.
- . 2001. "Social Cognitive Theory: An Agentic Perspective." *Annual Review of Psychology* 52 (1): 1–26.
- . 2006. "Guide for Constructing Self-Efficacy Scales." In *Self-Efficacy Beliefs of Adolescents*, edited by Frank Pajares and Timothy C. Urdan, 5:307–37. Information Age Publishing.
- Baron, R. M., and D. A. Kenny. 1986. "The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations." *Journal of Personality and Social Psychology* 51 (6): 1173–1182.
- Baron, Robert A. 1990. "Environmentally Induced Positive Affect: Its Impact on Self-Efficacy, Task Performance, Negotiation, and Conflict." *Journal of Applied Social Psychology* 20 (5): 368–384.
- Buuren, Stef van, and Karin Groothuis-Oudshoorn. 2011. "Mice: Multivariate Imputation by Chained Equations in R." *Journal of Statistical Software* 45 (3): 1–67.
- Choy, S. 2001. "Students Whose Parents Did Not Go to College: Postsecondary Access, Persistence, and Attainment. Findings from the Condition of Education, 2001." *Condition of Education - US Department of Education*, December.
- Chubin, D., K. Donaldson, B. Olds, and L. Fleming. 2008. "Educating Generation Net - Can U.S. Engineering Woo and Win the Competition for Talent?" *Journal of Engineering Education* 97 (3): 245–57. doi:10.1002/j.2168-9830.2008.tb00977.x.
- Costa, P. T., and R. R. McCrae. 1992. *Revised NEO Personality Inventory (NEO PI-R) and NEO Five-Factor Inventory (NEO-FFI)*. Psychological Assessment Resources (PAR).
- Duval-Couetil, Nathalie. 2013. "Assessing the Impact of Entrepreneurship Education Programs: Challenges and Approaches." *Journal of Small Business Management* 51 (3): 394–409.
- Duval-Couetil, Nathalie, T. Reed-Rhoads, and S. Haghighi. 2012. "Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes." *International Journal of Engineering Education* 28 (2): 425.
- Dyer, Jeffrey H., Hal B. Gregersen, and Clayton M. Christensen. 2008. "Entrepreneur Behaviors, Opportunity Recognition, and the Origins of Innovative Ventures." *Strategic Entrepreneurship Journal* 2 (4): 317–38.
- . 2011. "The Innovator's DNA: Mastering the Five Skills of Disruptive Innovators." *Harvard Business Review Press*.
- . 2016. "The Innovator's DNA: Assessment." *The Innovator's DNA. iDNA*. October. <http://innovatorsdna.com/assessment/>.

- Eesley, C.E., and W.F. Miller. 2012. "Impact: Stanford University's Economic Impact via Innovation and Entrepreneurship." Ewing Marion Kauffman Foundation.
- Eisenhardt, Kathleen M. 1989. "Building Theories from Case Study Research." *Academy of Management Review*, 532–550.
- "Epicenter: Creating a Nation of Entrepreneurial Engineers." 2017. January. <http://epicenter.stanford.edu/>.
- Farr, James L., and Cameron M. Ford. 1990. "Individual Innovation." In *Innovation and Creativity at Work: Psychological and Organizational Strategies*, edited by M. A. West and J. L. Farr, 63–80. Oxford, England: John Wiley & Sons.
- Ferguson, D. M. 2013. "Ph.D. Dissertation: How Engineering Innovators Characterize Engineering Innovativeness: A Qualitative Study - Purdue University." Ph.D. Dissertation, West Lafayette, IN: Purdue University.
- Ferguson, Daniel M, James E Cawthorne Jr., James Edwin, Benjamin Ahn, and Matthew W Ohland. 2013. "Engineering Innovativeness." *The Journal of Engineering Entrepreneurship* 4 (1): 1–16.
- Ferguson, Daniel M., Kathryn W Jablokow, Matthew W Ohland, and Şenay Purzer. 2017a. "The Diverse Personas of Engineering Innovators." *International Journal of Engineering Education* 33 (1(A)): 19–29.
- . 2017b. "Identifying the Characteristics of Engineering Innovativeness (in Press)." *Engineering Studies*, April.
- Ferguson, Daniel M., and Matthew W. Ohland. 2012. "What Is Engineering Innovativeness?" *International Journal of Engineering Education* 28 (2): 253–62.
- Fila, Nicholas D., Justin L. Hess, Paul D. Mathis, and Senay Purzer. 2015. "Challenges to and Development of Innovation Discovery Behaviors among Engineering Students." In *ASEE Annual Conference & Exposition*, 1–18. Seattle, WA.
- Gerber, Elizabeth, Caitlin K. Martin, Elizabeth Kramer, Jennie Braunstein, and Adam R. Carberry. 2012. "Developing an Innovation Self-Efficacy Survey." In *Frontiers in Education Conference*. Seattle, WA.
- Gilmartin, Shannon K., Helen L. Chen, Mark F. Schar, Qu Jin, George Toye, Angela M. Harris, Emily Cao, Emanuel Costache, Maximillian Reithmann, and Sheri D. Sheppard. 2017. "Designing a Longitudinal Study of Engineering Students' Innovation and Engineering Interests and Plans: The Engineering Majors Survey Project. EMS 1.0 and 2.0 Technical Report." Technical Report. Stanford, CA: Stanford University Designing Education Lab.
- Goldsmith, Ronald E. 1986. "Convergent Validity of Four Innovativeness Scales." *Educational and Psychological Measurement*. <http://psycnet.apa.org/psycinfo/1986-23437-001>.
- Gosling, S. D, P. J Rentfrow, and W. B Swann. 2003. "A Very Brief Measure of the Big-Five Personality Domains." *Journal of Research in Personality* 37 (6): 504–528.
- Gottfredson, Gary D., and John L. Holland. 1996. *Dictionary of Holland Occupational Codes*. Psychological Assessment Resources Inc.
- Hess, Justin L., Nicholas D. Fila, and Şenay Purzer. 2016. "The Relationship Between Empathic and Innovative Tendencies Among Engineering Students." *International Journal of Engineering Education* 32 (3): 1236–1249.
- Hu, Li-tze, and Peter M. Bentler. 1999. "Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria Versus New Alternatives." *Structural Equation Modeling: A Multidisciplinary Journal* 6 (1): 1–55.

- Jablokow, Kathryn W., and Michael J. Kirton. 2009. "Problem Solving, Creativity, and the Level-Style Distinction." In *Perspectives on the Nature of Intellectual Styles*, 137–68. Springer Publication.
- Jackson, Douglas Northrop. 1976. *Jackson Personality Inventory Manual*. Port Huron, MI: Research Psychologists Press.
- John, O. P, E. M Donahue, and R. L Kentle. 1991. "The Big Five Inventory—Versions 4a and 54." *Berkeley: University of California, Berkeley, Institute of Personality and Social Research*.
- Kanter, Rosabeth Moss. 1983. *The Change Masters*. New York: Simon & Schuster.
- . 1988. "When a Thousand Flowers Bloom: Structural, Collective, and Social Conditions for Innovations in Organizations." In *Research in Organizational Behaviour*, edited by B. M. Staw and L. L. Cummings, 10:169–211. Greenwich, CT: JAI Press.
- Kavanagh, David J., and Gordon H. Bower. 1985. "Mood and Self-Efficacy: Impact of Joy and Sadness on Perceived Capabilities." *Cognitive Therapy and Research* 9 (5): 507–525.
- "KEEN – Engineering Unleashed." 2017. January. <http://engineeringunleashed.com/keen/>.
- Kirton, Michael J. 1976. "Adaptors and Innovators: A Description and Measure." *Journal of Applied Psychology* 61 (5): 622–29.
- . 2003. *Adaption-Innovation: In the Context of Diversity and Change*. Psychology Press.
- Kleysen, R. F., and C. T. Street. 2001. "Toward a Multi-Dimensional Measure of Individual Innovative Behavior." *Journal of Intellectual Capital* 2 (3): 284–96.
- "Launchpad Central." 2017. January. <https://www.launchpadcentral.com/>.
- Lent, R. W., and S. D. Brown. 2006. "On Conceptualizing and Assessing Social Cognitive Constructs in Career Research: A Measurement Guide." *Journal of Career Assessment* 14 (1): 12–35.
- Lent, R. W., S. D. Brown, and G. Hackett. 1994. "Toward a Unifying Social Cognitive Theory of Career and Academic Interest, Choice, and Performance." *Journal of Vocational Behavior*, 79–122.
- Lent, R. W., Steven D. Brown, Hung-Bin Sheu, Janet Schmidt, Bradley R. Brenner, Clay S. Gloster, Gregory Wilkins, Linda C. Schmidt, Heather Lyons, and Dana Treistman. 2005. "Social Cognitive Predictors of Academic Interests and Goals in Engineering: Utility for Women and Students at Historically Black Universities." *Journal of Counseling Psychology* 52 (1): 84–92.
- Lent, R. W., Daniel Singley, Hung-Bin Sheu, Janet A. Schmidt, and Linda C. Schmidt. 2007. "Relation of Social-Cognitive Factors to Academic Satisfaction in Engineering Students." *Journal of Career Assessment* 15 (1): 87–97.
- Lerner, Richard M., and William Damon. 2011. "Young Entrepreneurs Study (YES)." *Young Entrepreneurs Study (YES)*. July. <http://ase.tufts.edu/iaryd/researchYes.htm>.
- Lintl, Florian M., Qu Jin, Shannon. K. Gilmartin, Helen L. Chen, Mark F. Schar, and Sheri D. Sheppard. 2015. "Starter or Joiner, Market or Socially-Oriented: Predicting Career Choice among Undergraduate Engineering and Business Students." In *Entrepreneurship Division*, Paper ID #12600:21. Seattle, WA.
- MacKinnon, David P., Chondra M. Lockwood, Jeanne M. Hoffman, Stephen G. West, and Virgil Sheets. 2002. "A Comparison of Methods to Test Mediation and Other Intervening Variable Effects." *Psychological Methods* 7 (1): 83.



- Mamaril, Natasha A., Ellen L. Usher, Caihong R. Li, D. Ross Economy, and Marian S. Kennedy. 2016. "Measuring Undergraduate Students' Engineering Self-Efficacy: A Validation Study." *Journal of Engineering Education* 105 (2): 366–395.
- Manly, Catherine A., and Ryan S. Wells. 2015. "Reporting the Use of Multiple Imputation for Missing Data in Higher Education Research." *Research in Higher Education* 56 (4): 397–409.
- Menold, Jessica, Kathryn W. Jablokow, Daniel M. Ferguson, Şenay Purzer, and Matthew W Ohland. 2016. "The Characteristics of Engineering Innovativeness: A Cognitive Mapping and Review of Instruments." *International Journal of Engineering Education* 32 (1(A)): 64–83.
- Nauta, Margaret M. 2010. "The Development, Evolution, and Status of Holland's Theory of Vocational Personalities: Reflections and Future Directions for Counseling Psychology." *Journal of Counseling Psychology* 57 (1): 11–22.
- "NSF Innovation Corps." 2017. January. [https://www.nsf.gov/news/special\\_reports/i-corps/index.jsp](https://www.nsf.gov/news/special_reports/i-corps/index.jsp).
- Nunnally, Jum C., and Ira H. Bernstein. 1994. *Psychometric Theory*. Third. New York, NY: McGraw-Hill.
- Schreiber, James B., Amaury Nora, Frances K. Stage, Elizabeth A. Barlow, and Jamie King. 2006. "Reporting Structural Equation Modeling and Confirmatory Factor Analysis Results: A Review." *The Journal of Educational Research* 99 (6): 323–38.
- Scott, Susanne G., and Reginald A. Bruce. 1994. "Determinants of Innovative Behavior: A Path Model of Individual Innovation in the Workplace." *Academy of Management Journal* 37 (3): 580–607.
- Sheu, Hung Bin, Robert W. Lent, Steven D. Brown, Matthew J. Miller, Kelly D. Hennessy, and Ryan D. Duffy. 2010. "Testing the Choice Model of Social Cognitive Career Theory Across Holland Themes: A Meta-Analytic Path Analysis." *Journal of Vocational Behavior* 76 (2): 252–264.
- Standards for Educational and Psychological Testing*. 2014. Washington DC: American Educational Research Association, American Psychological Association, National Council on Measurement in Education.
- Stanford University. 2016. "Engineering Majors Survey." *Epicenter*. October. <http://epicenter.stanford.edu/page/engineering-majors-survey#About>.
- Thatcher, Jason Bennett, and Pamela L. Perrewe. 2002. "An Empirical Examination of Individual Traits as Antecedents to Computer Anxiety and Computer Self-Efficacy." *Mis Quarterly*, 381–396.
- Thompson, Edmund R. 2007. "Development and Validation of an Internationally Reliable Short-Form of the Positive and Negative Affect Schedule (PANAS)." *Journal of Cross-Cultural Psychology* 38 (2): 227–42.
- Toutkoushian, Robert K., Robert S. Stollberg, and Kelly A. Slaton. 2015. "Talking 'bout My Generation: Defining 'First-Generation Students' in Higher Education Research." In *Association for the Study of Higher Education - 40th Annual Conference*. Denver, CO.
- "UnternehmerTUM | Innovation - Business Creation - Venture Capital." 2017. January. <https://www.unternehmertum.de/index.html>.
- Vancouver, Jeffery B., Charles M. Thompson, E. Casey Tischner, and Dan J. Putka. 2002. "Two Studies Examining the Negative Effect of Self-Efficacy on Performance." *Journal of Applied Psychology* 87 (3): 506.



“VentureWell - Home.” 2017. *VentureWell*. January. <https://venturewell.org/>.

Watson, David, Lee A. Clark, and Auke Tellegen. 1988. “Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales.” *Journal of Personality and Social Psychology* 54 (6): 1063–70.

## Appendix A

Comparison of Dyer et al. with ISE item wording:

<b>Dyer et al. Innovative Behavior Scale (IBS)</b>		<b>Innovation Self-Efficacy Scale and Items*</b>
<i>Below is a list of behaviors. Please think about how much you <b>agree</b> or <b>disagree</b> that that these behaviors describe your behavior.</i>		<i>Below is a list of activities. Please think about how <b>confident</b> you are in your ability to do these activities. How <b>confident</b> are you in your ability to ...</i>
7-point scale: Strongly Disagree to Strongly Agree		5-point scale: Not Confident to Extremely Confident
Item	Questioning	
Q.1	I am always asking questions	Ask a lot of questions
Q.2	I am constantly asking questions to get at the root of the problem	Ask the right questions to get to the root of a problem
Q.3	Others are frustrated by the frequency of my questions	Ask more questions than my classmates
Q.4	I often ask questions that challenge the status quo	Ask the kind questions that change the way others think about a problem
Q.5	I regularly ask questions that challenge others' fundamental assumptions	Ask questions that challenge fundamental assumptions
Q.6	I am constantly asking questions to understand why products and projects underperform	Ask questions to understand why projects or designs underperform
<b>Observing</b>		
O.1	New business ideas often come to me when directly observing how people interact with products and services	Think of new ideas by carefully watching people interact with products and services
O.2	I have a continuous flow of new business ideas that come through observing the world	Generate new ideas by observing the world
O.3	I regularly observe customers' use of our company's products and services to get new ideas	Observe how people use products and services to help me get new ideas
O.4	By paying attention to everyday experiences, I often get new business ideas.	Pay attention to everyday experiences as a way to get new ideas
<b>Experimenting</b>		
E.1	I love to experiment to understand how things work and to create new ways of doing things	Experiment as a way to understand how things work
E.2	I frequently experiment to create new ways of doing things	Experiment to create new ways of doing things
E.3	I am adventurous, always looking for new experiences	Be adventurous and seek out new experiences
E.4	I actively search for new ideas through experimenting	Actively search for new ideas through experimenting
E.5	I have a history of taking things apart	Take things apart to see how they work
<b>Idea Networking</b>		
I.1	I have a network of individuals whom I trust to bring a new perspective and refine new ideas	Build a network of people whom I trust to bring a new perspective and refine my ideas
I.2	I attend many diverse professional and/or academic conferences outside of my industry/profession	Seek the advice of students and faculty outside my circle of contacts to test ideas
I.3	I initiate meetings with people outside of my industry to spark ideas for a new product, service, or customer base	Reach out to people outside of my academic major to spark ideas for a new product or service
I.4	I have a large network of contacts with whom I frequently interact to get ideas for new products, services, and customers	Build a large network of contacts with whom I can interact with to get ideas for new products or services
<b>Associational Thinking</b>		
A.1	N/A	Connect concepts and ideas that appear, at first glance, to be unconnected
A.2	N/A	Connect ideas from different and diverse areas

\* Items shaded are used in the ISE.5 scale. Also see Appendix C.

## Appendix B – Modified Dyer et al. Innovation Behavior Scale Descriptives (Study 1)

Variable	Item	Mean $\bar{x}$	SD $\sigma$	Median	Skew	Kurtosis
<b>Questioning</b>						
Q.1	Ask a lot of questions	3.35	1.10	3.00	-0.25	-0.58
Q.2	Ask the right questions to get to the root of a problem	3.43	0.85	3.00	-0.22	0.09
Q.3	Ask more questions than my classmates	2.85	1.09	3.00	0.12	-0.63
Q.4	Ask the kind questions that change the way others think about a problem	3.29	0.99	3.00	-0.17	-0.30
Q.5	Ask questions that challenge fundamental assumptions	3.25	0.98	3.00	-0.14	-0.24
Q.6	Ask questions to understand why projects or designs underperform	3.52	0.94	4.00	-0.38	0.07
<b>mean.Q</b>	$\alpha = .82$	<b>3.28</b>	<b>0.73</b>	<b>3.17</b>	<b>-0.06</b>	<b>-0.19</b>
<b>Observing</b>						
O.1	Think of new ideas by carefully watching people interact with products and services	3.46	0.92	3.00	-0.29	-0.11
O.2	Generate new ideas by observing the world	3.61	0.93	4.00	-0.34	-0.15
O.3	Observe how people use products and services to help me get new ideas	3.48	0.88	4.00	-0.26	-0.14
O.4	Pay attention to everyday experiences as a way to get new ideas	3.61	0.94	4.00	-0.40	-0.08
<b>mean.O</b>	$\alpha = .86$	<b>3.54</b>	<b>0.77</b>	<b>3.50</b>	<b>-0.37</b>	<b>0.48</b>
<b>Experimenting</b>						
E.1	Experiment as a way to understand how things work	3.64	0.93	4.00	-0.35	-0.16
E.2	Experiment to create new ways of doing things	3.49	0.94	3.00	-0.21	-0.19
E.3	Be adventurous and seek out new experiences	3.79	0.92	4.00	-0.56	0.16
E.4	Actively search for new ideas through experimenting	3.46	0.92	3.00	-0.24	-0.18
E.5	Take things apart to see how they work	3.73	1.01	4.00	-0.40	-0.49
<b>mean.E</b>	$\alpha = .84$	<b>3.62</b>	<b>0.74</b>	<b>3.60</b>	<b>-0.42</b>	<b>0.55</b>
<b>Idea Networking</b>						
I.1	Build a network of people whom I trust to bring a new perspective and refine my ideas	3.39	0.94	3.00	-0.30	-0.06
I.2	Seek the advice of students and faculty outside my circle of contacts to test ideas	3.21	1.02	3.00	-0.21	-0.34
I.3	Reach out to people outside of my academic major to spark ideas for a new product or service	3.27	1.06	3.00	-0.37	-0.34
I.4	Build a large network of contacts with whom I can interact with to get ideas for new products or services	3.20	1.02	3.00	-0.22	-0.45
<b>mean.I</b>	$\alpha = .81$	<b>3.27</b>	<b>0.81</b>	<b>3.25</b>	<b>-0.24</b>	<b>-0.04</b>
<b>mean.IBS</b>		<b>3.42</b>	<b>0.64</b>	<b>3.42</b>	<b>-0.30</b>	<b>0.83</b>
<b>Associational Thinking</b>						
A.1	Connect concepts and ideas that appear, at first glance, to be unconnected	3.40	0.87	3.00	-0.17	-0.20
A.2	Connect ideas from different and diverse areas	3.54	0.86	4.00	-0.41	0.30
<b>Four Item</b>	$\alpha = .65$	<b>3.45</b>	<b>0.70</b>	<b>3.50</b>	<b>-0.35</b>	<b>0.44</b>
<b>Five Item</b>	$\alpha = .79$	<b>3.44</b>	<b>0.67</b>	<b>3.50</b>	<b>-0.36</b>	<b>0.68</b>

Notes: n = 334, mean.IBS = mean of the 19 original Dyer et al. items, Four Item = Q.1, O.2, E.1, I.4 Five Item = Q.1, O.2, E.1, I.4, A.1

## Appendix C

### Very Brief - Innovation Self-Efficacy Scale (ISE.5)

How confident are you in your ability to do each of the following at this time?

Not Confident (1)	Slightly Confident (2)	Moderately Confident (3)	Very Confident (4)	Extremely Confident (5)	Prefer Not to Answer (-9)
----------------------	---------------------------	-----------------------------	-----------------------	----------------------------	------------------------------

Ask a lot of questions (*Questioning*)

Generate new ideas by observing the world (*Observing*)

Experiment as a way to understand how things work (*Experimenting*)

Build a large network of contacts with whom you can interact to get ideas for new products or services (*Idea Networking*)

Connect concepts and ideas that appear, at first glance, to be unconnected (*Associational Thinking*)

### Innovation Interests Scale (INI)

How much interest do you have in:

Very Low Interest (1)	Low Interest (2)	Medium Interest (3)	High Interest (4)	Very High Interest (5)	Prefer Not to Answer (-9)
--------------------------	---------------------	------------------------	----------------------	---------------------------	------------------------------

Experimenting in order to find new ideas

Giving an “elevator pitch” or presentation to a panel of judges about a new product or business idea

Finding resources to bring new ideas to life

Developing plans and schedules to implement new ideas

Conducting basic research on phenomena in order to create new knowledge

### Career Goals: Innovative Work (CGIW)

How important is it to you to be involved in the following job or work activities in the first five years after you graduate?

Not Important (1)	Slightly Important (2)	Moderately Important (3)	Very Important (4)	Extremely Important (5)	Prefer Not to Answer (-9)
----------------------	---------------------------	-----------------------------	-----------------------	----------------------------	------------------------------

Searching out new technologies, processes, techniques, and/or product ideas

Generating creative ideas

Promoting and championing ideas to others

Investigating and securing resources needed to implement new ideas

Developing adequate plans and schedules for the implementation of new ideas

Selling a product or service in the marketplace